MeerKAT, SKA and Source Separation

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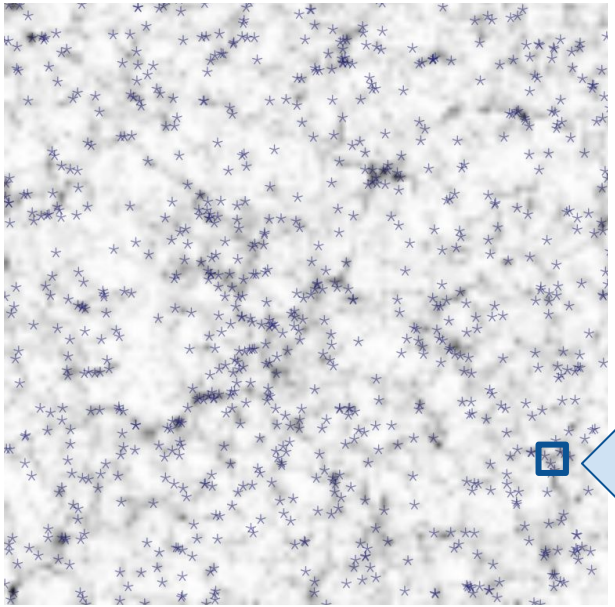
Observatoire de la Côte d'Azur

6 Juin 2024 - Joint ARGOS TITAN TOSCA - Heraklion

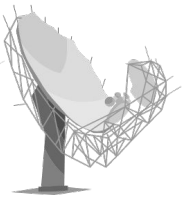
Intensity Mapping



costly to resolve each HI galaxy
and limited to local Universe

How can we efficiently observe cosmological volumes?

Intensity Mapping:
total intensity of the 21cm emission line in a **large pixel** (low spatial resolution)



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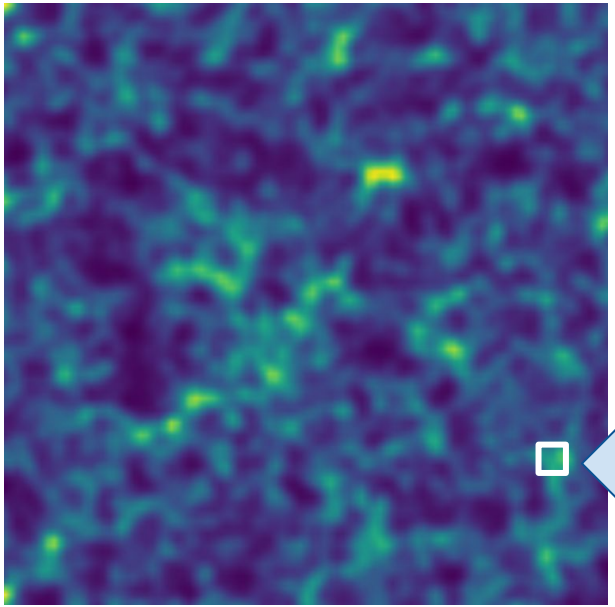

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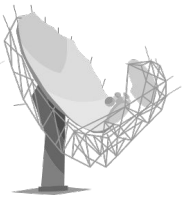

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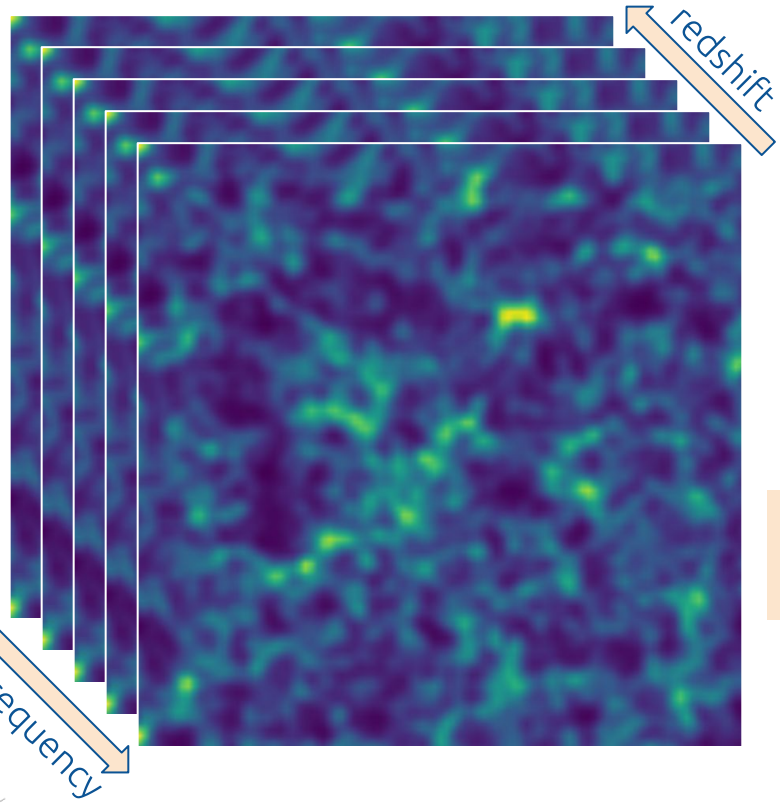

costly to resolve each HI galaxy
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How can we efficiently observe
cosmological volumes?

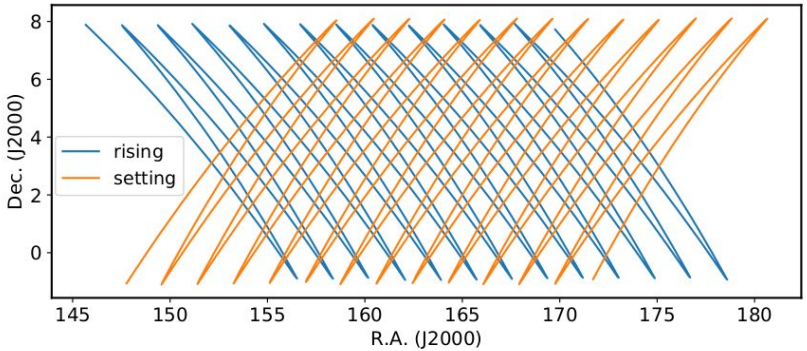
one-to-one correspondence frequency-redshift
high spectral resolution (tomography)

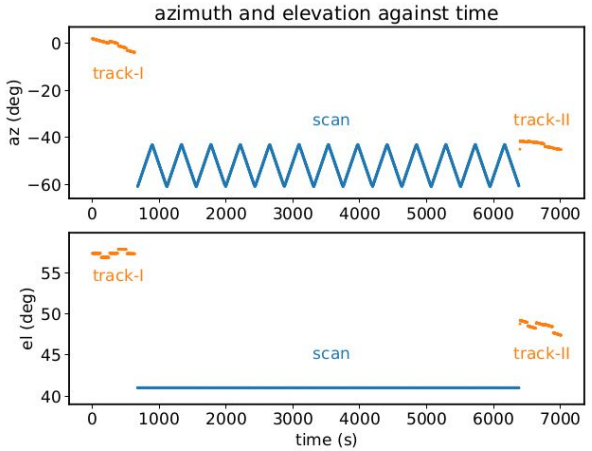
Key cosmological probe

Intensity Mapping with MeerKAT

Santos et al. 2017, Wang et al. 2021

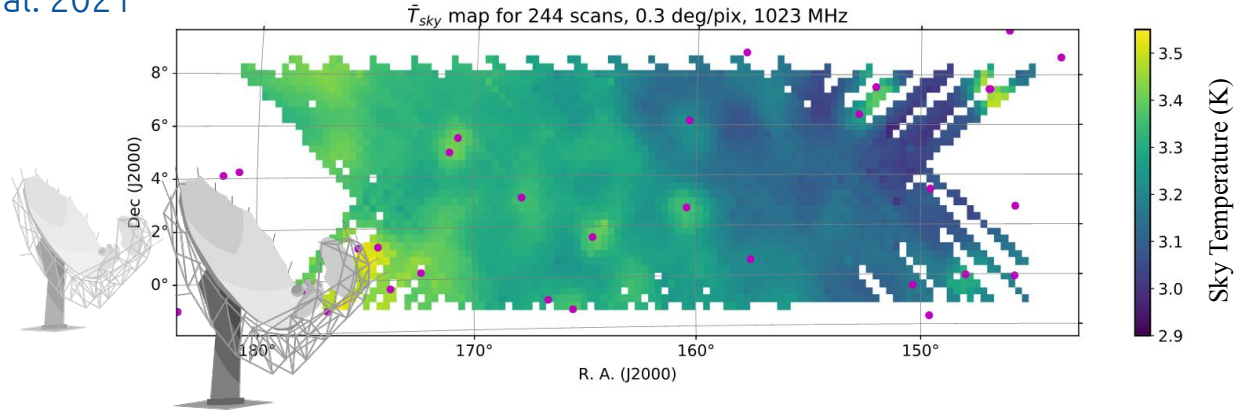
Antennas	All 64 MeerKAT dishes
Observation mode	Single-dish
Frequency range	0.856-1.712 GHz
Frequency resolution	0.2 MHz
Time resolution	2s
Exposure time	1.5hr x 7 scans
Target field	WiggleZ 11hr field ($10^\circ \times 30^\circ$)





MeerKAT observations

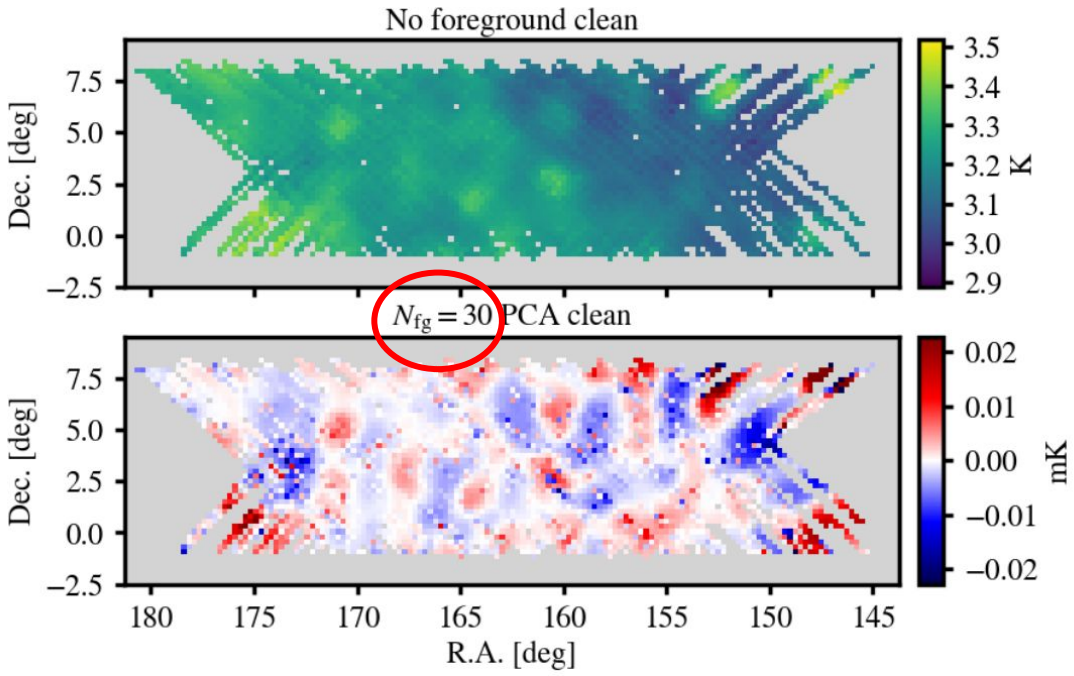
Wang et al. 2021

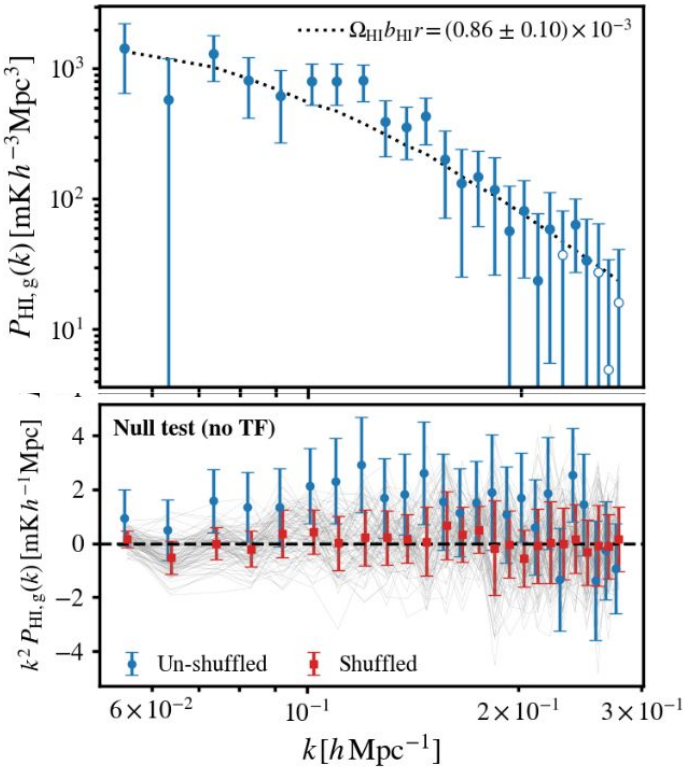


MeerKLASS: 64 MeerKAT antennas used in single-dish mode
PI: M. G. Santos (Santos et al. 2017)

- ❏ first successful calibration of intensity mapping data from MeerKAT
- ❏ L-band: 850-1700 MHz (4096 channels)

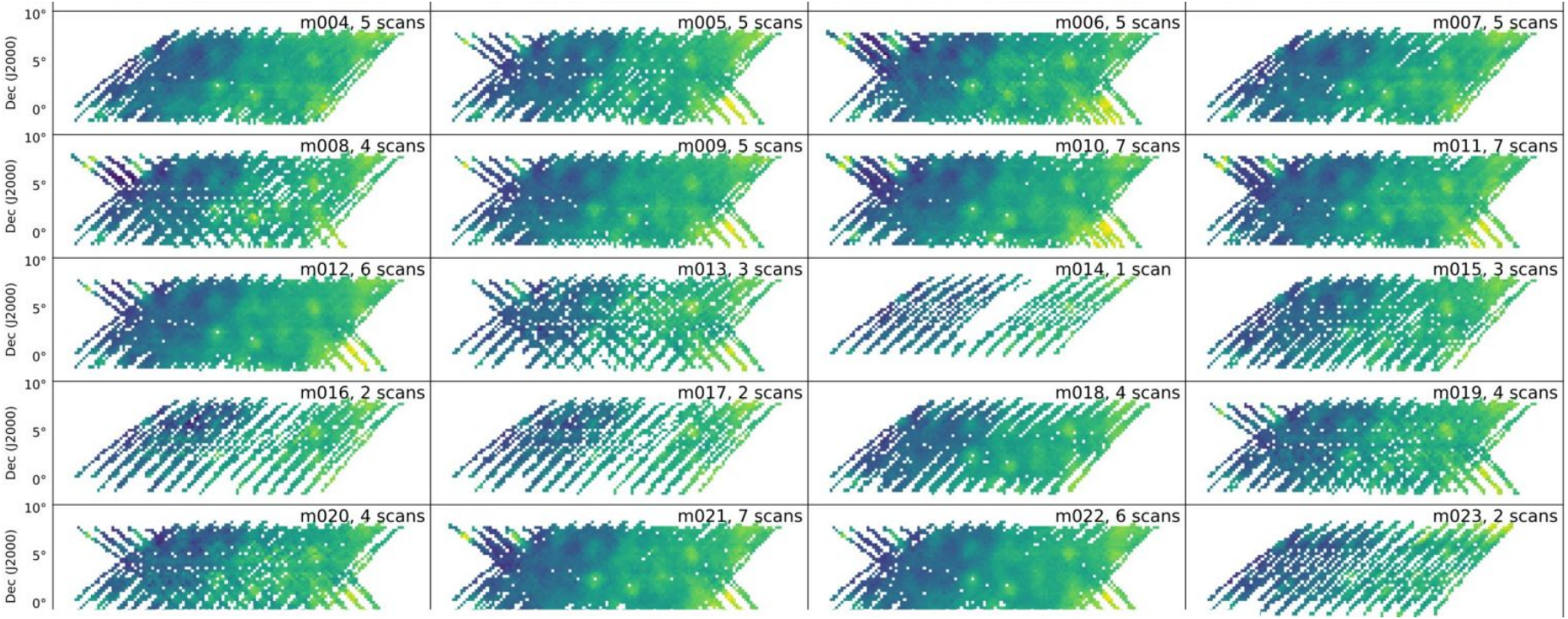
MeerKLASS observations





Cunnington et al. 2022

MeerKLASS maps



MeerKLASS maps

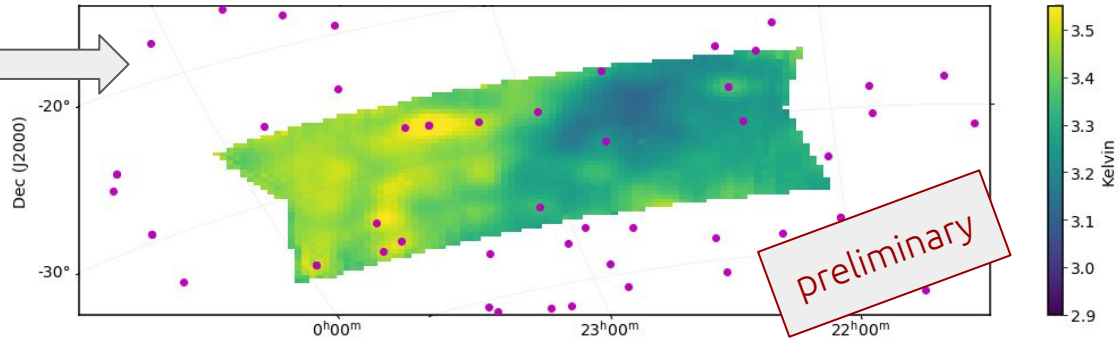
MeerKLASS ongoing

Improved cleaning/comparison on 2019 L-band data

L-band: 41x1.5h scans

UHF-band: 50x1.5h scans

L-band: split data to reduce systematics cross-correlating different blocks



New calibration pipeline(s):

KATcali: improved RFI flagging, improved sky model with self-calibration

Ivory/MuSEEK: new improved modular plugin-based architecture

easily adaptable to SKA

On-the-fly (OTF) interferometry
commensal IM and interferometric imaging (no dedicated OTF obs mode on MeerKAT but engineering & commissioning team involved)

End-to-end

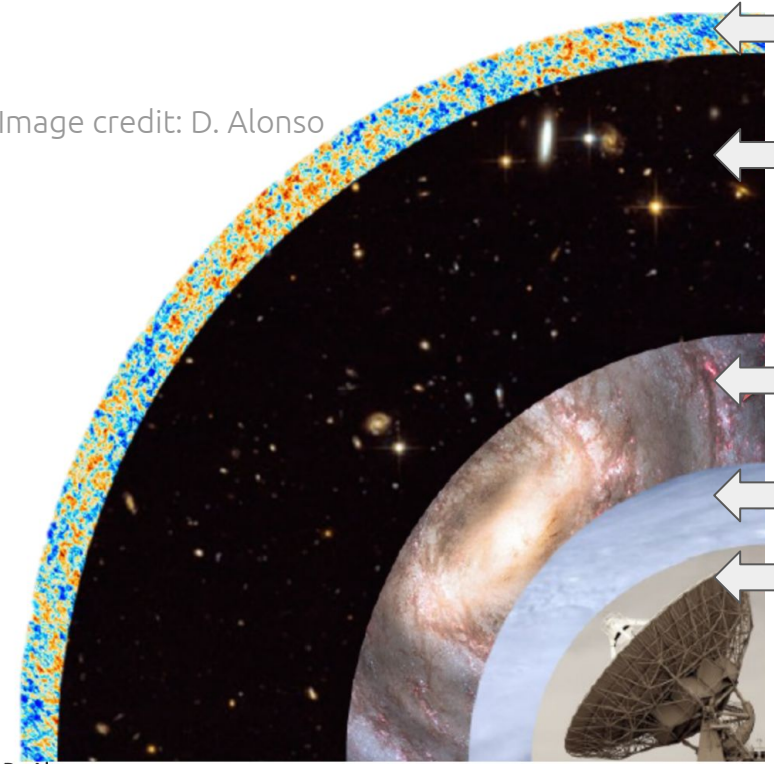


Image credit: D. Alonso

realistic mocks

- 21cm signal maps
- extra-galactic emission
- Galactic emission
- instrumental and systematic effects

analysis pipeline:
TOD, beam convolution, calibration errors, …

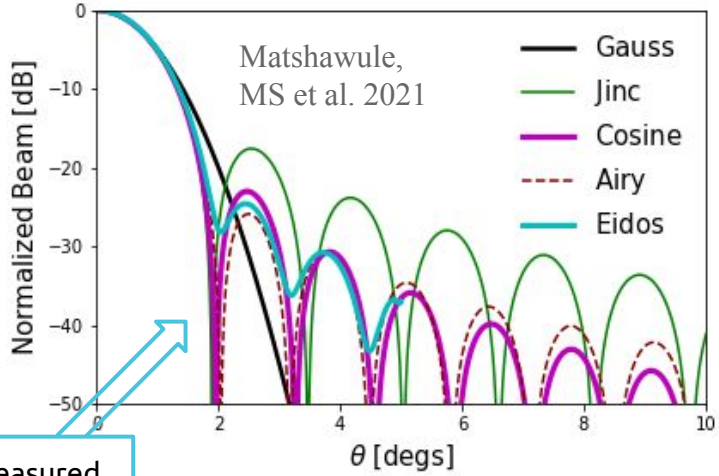
Source separation

power spectrum

cosmological parameter constraints

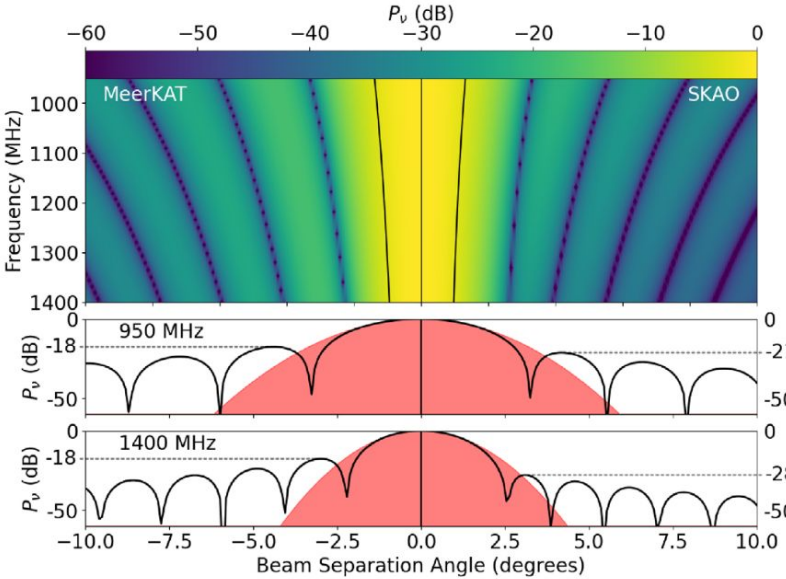
Improving simulations

- MeerKAT beam has **side-lobes** (same for SKA-MID)
- a strong point source in the side-lobes contaminates the signal and can complicate the foreground subtraction



Eidos: measured
Asad et al. 2020

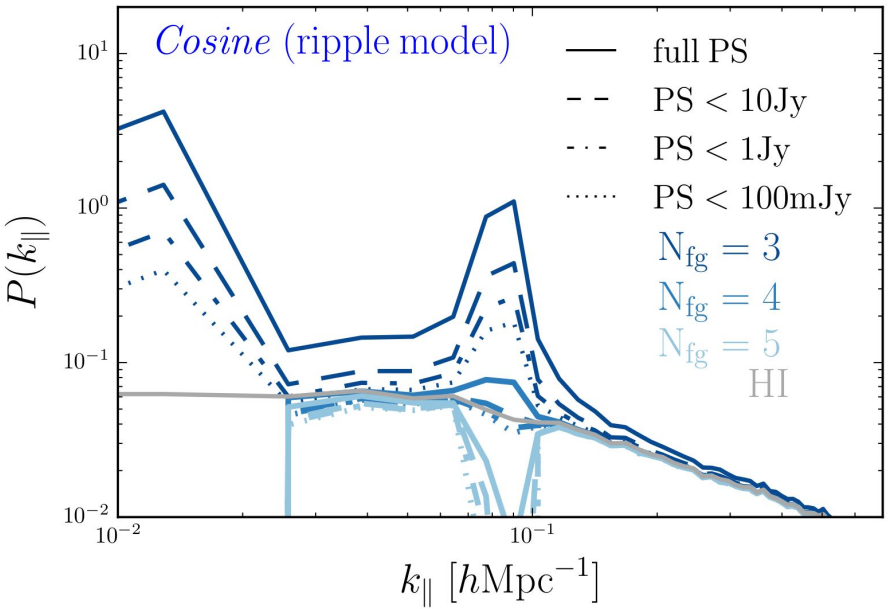
Airy beam
Harper et al. (2018)



MS et al. 2022

The beam evolves with frequency

Effect of the telescope beam

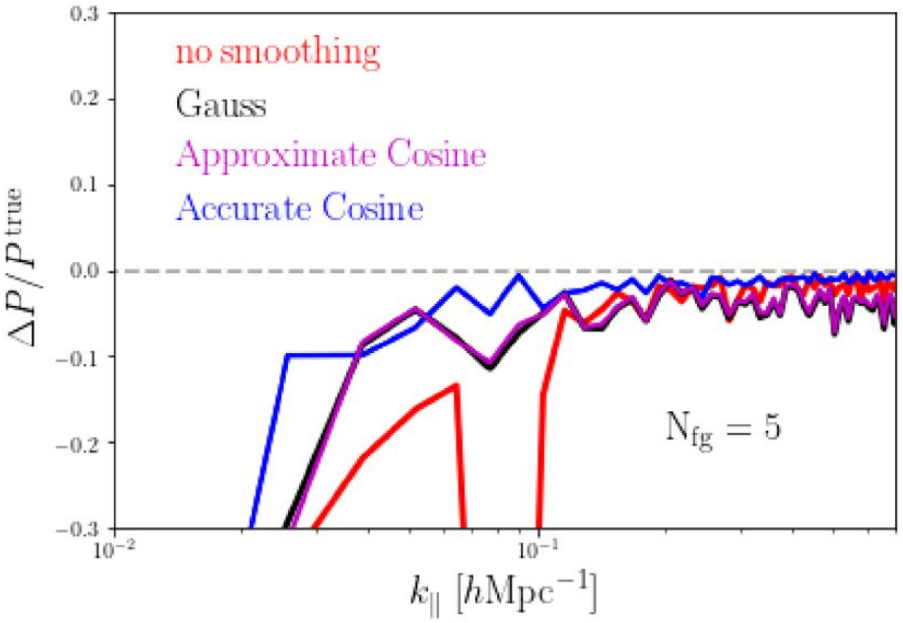


Matshawule, MS et al. 2021

a realistic **MeerKAT** beam model:
side-lobes (cosine) and a non-trivial frequency evolution (ripple)

- **point sources** and synchrotron spatial structures coupled with the beam **complicate the cleaning**
- Careful **beam-deconvolution** alleviates the problem but need to be careful for precision cosmology
- What about the measured 2D beam?

Effect of the telescope beam



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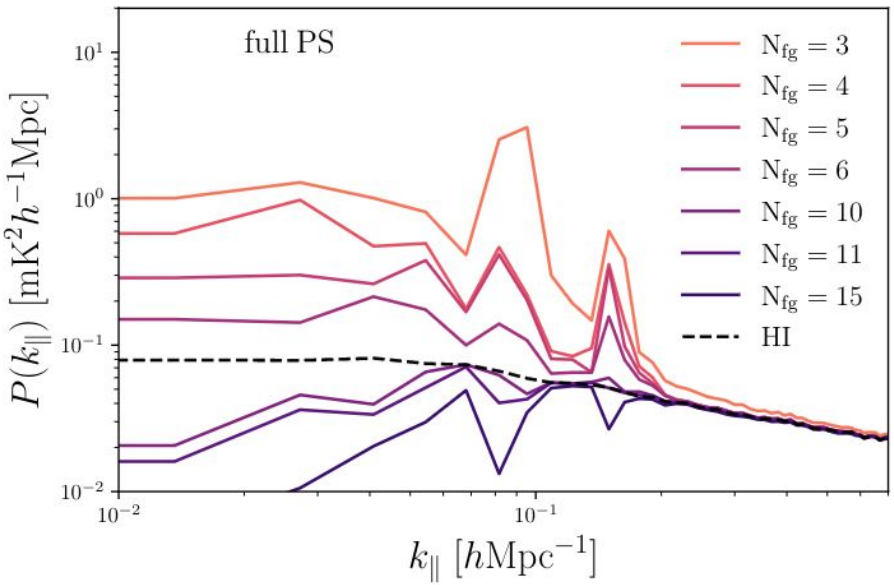

MS, Matshawule et al. *in prep*

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Foreground subtraction challenge

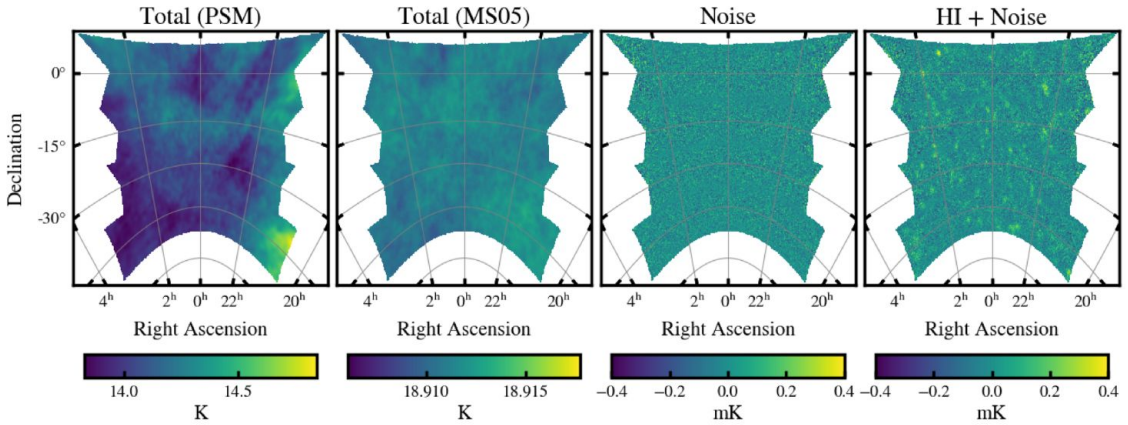
(subset) of the SKA Cosmo IM Focus Group

Isabella Paola Carucci, Steve Cunnington, Ze Fonseca, Stuart Harper, Mel Irfan, Alkistis Pourtsidou, Marta Spinelli, Laura Wolz

Project setup:

- various foreground models and realistic HI maps
- instrumental modeling MeerKAT-like and SKAO-like
- 9 different foreground removal methods (PCA, FastICA, …)

Blind challenge to discover weaknesses and strengths of the various methods

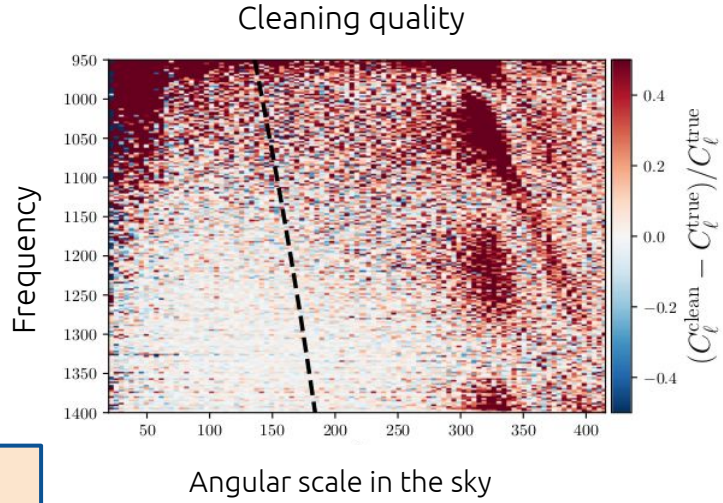


given IM “data”,
would your favorite method extract the cosmological signal?

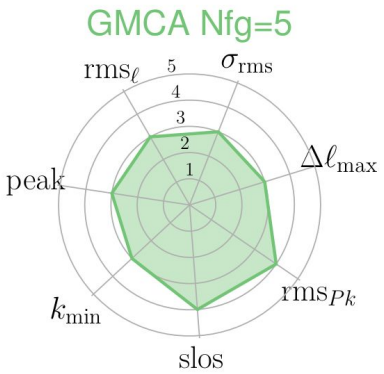
Foreground subtraction challenge

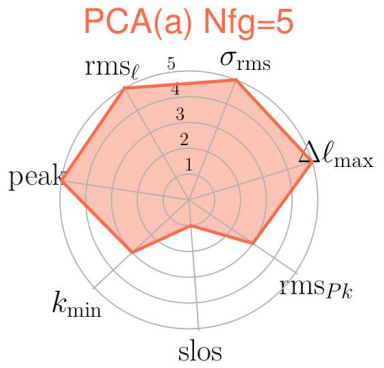
- How much can **instrument/foregrounds coupling** impact the signal reconstruction?
- definition of statistics and metrics to evaluate the relative performances

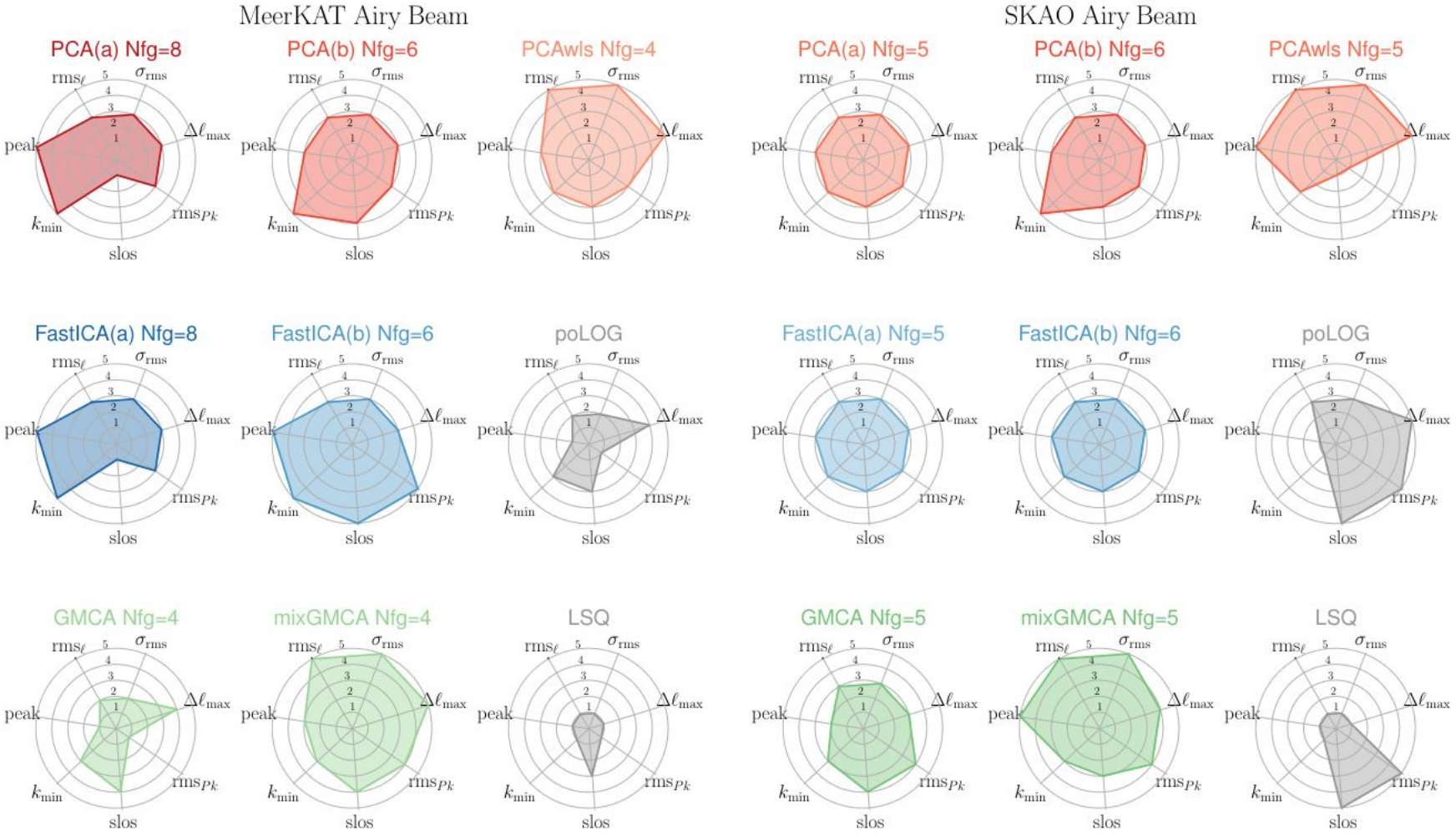
Realistic instrumental effects inevitably **complicate** the foreground cleaning



MS et al. (2022)

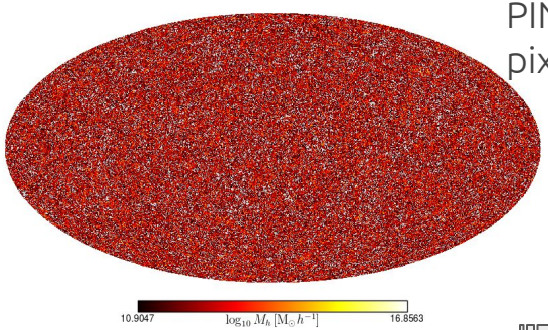


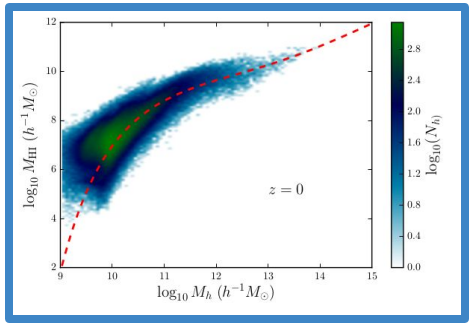



MeerKAT Airy Beam
SKAO Airy Beam
PCA(a) Nfg=8
PCA(b) Nfg=6
PCAwls Nfg=4
PCA(a) Nfg=5
PCA(b) Nfg=6
PCAwls Nfg=5
FastICA(a) Nfg=8
FastICA(b) Nfg=6
poLOG
FastICA(a) Nfg=5
FastICA(b) Nfg=6
poLOG
GMCA Nfg=4
mixGMCA Nfg=4
LSQ
GMCA Nfg=5
mixGMCA Nfg=5
LSQ
rms_ℓ
σ_{rms}
$\Delta\ell_{\max}$
rms_{Pk}
slos
$k_{\min}$
peak
1
2
3
4
5

Hi-Probe POPulator (HiP-POP)

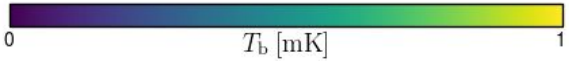
PINOCCHIO full sky light-cone
pixelized with Healpix





MHI (ra,dec, u)

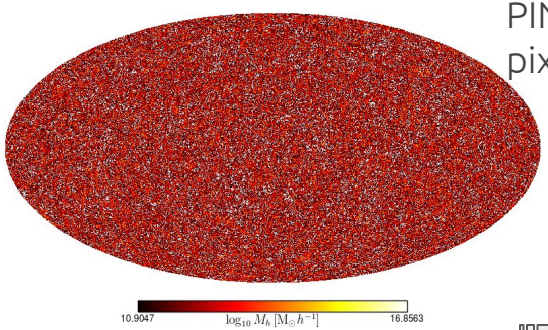
Tb [mK]

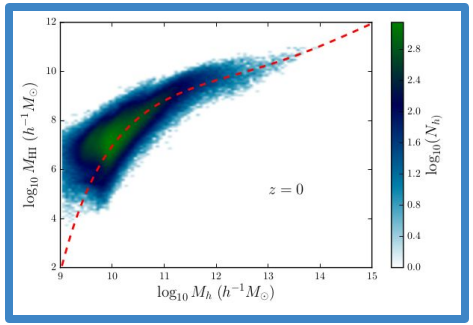


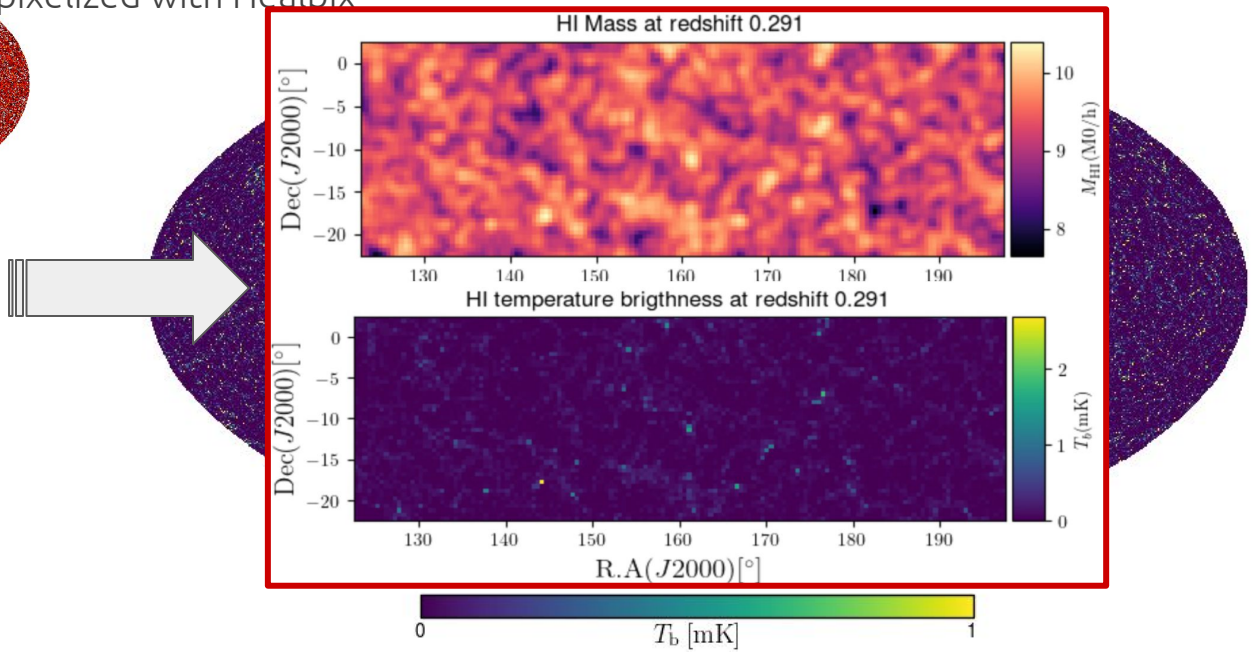
Too big halos “spread” with NFW in nearby pixels

Hi-Probe POPulator (HiP-POP)

PINOCCHIO full sky light-cone
pixelized with Healpix







Too big halos “spread” with NFW in nearby pixels

Towards the SKA Observatory

We have:

21cm intensity mapping data that we are not able to clean *(without being very aggressive or using cross-correlation)*

Simulations that are *still* not a very good representation of the data

Cleaning methods that have not been tested in realistic scenarios

We would like:

More and better data

More realistic simulations mimicking the data

More sophisticated cleaning methods tested on more realistic simulations

Final aim:

A 21cm (auto) power spectrum detection validated with realistic simulations and tested with various and robust cleaning methods